TECHNICAL NOTES

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS.

No. 141

EXPERIMENTS WITH A BUILT-IN OR FUSELAGE RADIATOR.

By C. Wieselsberger.

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The experiments described in the following report were performed at the request of the Technical Section of the Air Service (Flugzeugmeisterei), with a view to determining whether radiators having similar cooling properties offer less resistance when incorporated in the fuselage, than when the hitherto customary arrangement is employed, with the radiator in the free air current more or less independent of the fuselage. The following tests were carried out in this connection:

1. Measurement of the fuselage resistance when a special hood <u>s</u> is fitted to the fuselage, in order to produce a suitably shaped nose.

2. Measurement of the fuselage resistance with the shape of the nose made to suit the radiator incorporated in the same. The radiator was closed so that no air could pass through it.

3. Measurement of the fuselage resistance with the radiator incorporated in the same, with air passing through it and escaping laterally through vents. All the vents (9 on each side) were open.

4. Similar conditions as in 3, but with only the four front vents open.

* From Technische Berichte, Volume III, Part 4. Communication from the Göttingen Aerodynamic Laboratory, (1918).

5. Similar conditions as in 3, but with only the four rear vents open.
6. Similar conditions as in 3, but with the cooling air escaping through the open end of the fuselage.
7. Measurement of the radiator resistance alone.

In order to obtain the cooling effect, it is necessary to circulate a definite quantity of air through the radiator. The quantity of air required was observed in tests 3 to 7, and formed the basis for the measurement of the cooling effect.

The fuselage model of a D airplane, one-fifth size, was used for these experiments, as shown in Fig. 1. The radiator was replaced, as in former experiments with models, by two frames covered with fine wire netting, with a total frontal surface of about 56 m^2 (8.68 in^2). The model radiator is so constructed that it offers the same resistance to air flow as a real radiator, while the side vents for discharging the cooling air are formed by pieces of sheet metal fitting tangentially to the outer surface of the fuselage, in order that the smooth surface of the fuselage should be affected as little as possible. Internally, they are bent over and present a rounded surface which has the effect of decreasing the air resistance. The total area of the vents is approximately equal to the front surface of the radiator. The engine, for the purpose of imitating the air flow in a real fuselage, is represented by a wooden model m, of similar shape. All the experiments were made without a propeller.

Experiments 1 to 7 give the resistance of the fuselage and the radiator and enable a comparison between the arrangement of the radiator apart from the fuselage and with the radiator incorporated in the fuselage. The hood _s_ on the nose of the fuselage in test 1 gives a favorable shape as regards air resistance. Experiment 2, with the hood removed and the radiator closed so that the air cannot pass through it, indicates the extent to which the air resistance is increased by the less favorable shape of the nose of the fuselage, necessitated by the position of the radiator. Experiment 6, which has hardly any practical importance in connection with these tests and in which the rear portion _e_, of the fuselage was removed, served to determine the quantity of air that passed through the radiator and the air velocity in the effective discharge area _p_ behind the radiator. The measurements would appear, however, to be valuable in certain other aspects, inasmuch as the velocity in the section behind the radiator may alter when the point at which the cooling air is discharged is varied, or in other words, the readings may not be identical, when the air is discharged through the vents and through the end of the fuselage. As, however, the same readings were obtained, it may be assumed that the quantities of air as determined are approximately correct. The quantity of air discharged was calculated from the drop in velocity which takes place as the air passes through the radiator.

The results of the tests in Tables I to VII are shown graphically in Figs. 2 and 3. The curves 1 to 7 correspond with the numbers of the above-mentioned experiments. Curve 2, Fig. 2, shows that the resistance surface S_p, of the fuselage is only slightly increased when the front of the fuselage is altered by a built-in radiator. Curves 3 to 6 show that the resistance reaches a maximum when all the vents are open, and a minimum when the air is discharged only through the four rear vents on both sides. Fig. 3 demonstrates that resistance is closely connected with the quantities flowing through at any given time, which fact is of the greatest importance. The maximum flow of air takes place when the resistance is greatest. In the experiments submitted, the quantity flowing through is greatest when the fuselage and the radiator are separate. A comparison of experiments 4 and 5 shows that the quantities of air circulated with equal vent areas are greater when the rear vents are closed. At this point of the fuselage, there is a partial vacuum which increases the drop in pressure between the inlet and outlet openings.

The resistance of the surface of the radiator plus that of the fuselage (shape of fuselage according to experiment 1) is shown by curve 8, Fig. 2. Since, however, the radiator model consists almost entirely of the permeable part without the water tank, which of course is required for the actual radiator and increases the front surface, we obtain, in this instance, a resistance surface which is too small.

It now becomes necessary to compare the actual radiators, in order to arrive at a correct solution of the problem. For this purpose the curves 9 and 10 have been added, recalculated for the resistance surface of 150/160 HP Mercedes and 150/160 HP Rumpler radiators. The relation between the resistance and the quantity of air passing through, is brought out still more distinctly in Fig. 4. The resistance surface evidently increases in proportion to the quantity of air flowing through, when the fuselage and the radiator are separate.

An additional radiator placed beside the original one would, of course, double the quantity of air flowing through, but the surface resistance would also be doubled. The relation between resistance surface and the quantity of air flowing through is, in this case, shown by the dash straight lines which cut the ordinates, and indicate the resistance surface of the fuselage. Lateral discharge of the cooling air gives the continuous lines shown, each of which is determined by three points. These are, however, some distance from the lines which represent the discharge through the open end of the fuselage. If the lines representing the discharge through the vents are extended to the right (for instance, by an amount equal to 50 m/sec (164 ft/sec) air velocity, in order to reach the discharge rate through the radiator in a free air current and this velocity is considered necessary for the cooling of the radiator), we obtain a smaller resistance surface than in the free air current (point _e_). The resistance is still further reduced if we use the actual radiators mentioned above, instead of the radiator model which gave the dash lines. The lines corresponding to 50 m/sec are shown dotted. When the radiator is incorporated in the fuselage, it is only possible to obtain a quantity equal to that which flows through the radiator in the free air current, provided the lateral outlet vents are widened or the quantity of air is increased by some special means, such as fans. Whether it will be possible, in practice, to obtain the necessary cooling effect in this way, together with reduced resistance of the fuselage, can not be decided here, since it is a question of construction. If the fuselage radiator is increased in size in order to pass the necessary quantity of air through it, the advantage of a smaller resistance will, under certain circumstances, be doubtful, owing to the greater weight of the radiator. Should it, however, be possible to obtain the required flow of air without introducing other detrimental features, the experiments show that the arrangement with the radiator incorporated in the fuselage gives about 20% less resistance than when the radiator is separate, provided the latter is equipped with the above-mentioned Mercedes radiator. A comparison between the fuselage radiator and the separately arranged Rumpler radiator shows about 14% less resistance in favor of the former.

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Table I.

Experiment 1. Fuselage with hood.

Pressure, q		Velocity, V		Resistance, D		Resistance surface, S_D	
kg/m²	lb/ft²	m/sec	ft/sec	g	lb	cm²	in²
25.3	5.18	20.1	65.94	85	.187	33.6	5.21
39.5	8.09	25.1	82.35	127	.280	32.1	4.98
57.1	11.69	30.2	99.08	181	.399	31.7	4.91
77.8	15.93	35.3	115.81	242	.534	31.2	4.84
101.8	20.85	40.3	132.22	312	.688	30.6	4.74
128.7	26.36	45.4	148.95	384	.847	29.8	4.62

Table II.

Experiment 2. Fuselage with blunt nose.

Pressure, q		Velocity, V		Resistance, D		Resistance surface, S_D	
kg/m²	lb/ft²	m/sec	ft/sec	g	lb	cm²	in²
25.4	5.20	20.0	65.62	90	.198	35.4	5.49
39.6	8.11	25.0	82.02	137	.302	34.5	5.35
57.0	11.67	29.9	98.10	193	.425	33.9	5.25
77.9	15.95	35.0	114.83	257	.567	33.1	5.13
102.0	20.89	40.0	131.23	330	.728	32.3	5.01
128.6	26.34	45.0	147.64	408	.899	31.7	4.91

Table III.

Experiment 3. Cooling air discharged through 9 vents on each side.

Resistance.

Pressure, q		Velocity, V		Resistance, D		Resistance surface S_D	
kg/m²	lb/ft²	m/sec	ft/sec	g	lb	cm²	in²
25.3	5.18	20.1	65.94	163	.359	64.5	10.00
39.6	8.11	25.2	82.68	250	.551	63.1	9.78
57.1	11.69	30.2	99.08	356	.785	62.4	9.67
77.6	15.89	35.2	115.49	477	1.052	61.4	9.52
101.6	20.81	40.3	132.22	616	1.358	60.7	9.41
129.0	26.42	45.4	148.95	764	1.684	59.3	9.19

Table III (Cont.)

Air flow.

Pressure, q		Velocity, V		Velocity through radiator section, V_r		Quantity of air flowing through, Q	
kg/m²	lb/ft²	m/sec	ft/sec	m/sec	ft/sec	l/sec	ft³/sec
13.8	2.83	14.8	48.56	7.1	23.29	39.6	1.40
24.8	5.08	19.9	65.29	9.5	31.17	53.1	1.88
38.9	7.97	24.9	81.69	11.8	38.71	66.0	2.33
56.5	11.57	30.0	98.42	14.4	47.24	81.0	2.86
76.9	15.75	35.0	114.83	16.8	55.12	94.4	3.33
100.5	20.58	40.0	131.23	19.0	62.34	106.0	3.74

Table IV.

Experiment 4. Cooling air discharged through 4 forward vents on each side.

Resistance.

Pressure, q		Velocity, V		Resistance, D		Resistance surface, S_D	
kg/m²	lb/ft²	m/sec	ft/sec	g	lb	cm²	in²
25.2	5.16	20.1	65.94	130.7	.288	52.0	8.06
39.6	8.11	25.2	82.68	205	.452	51.8	8.03
57.2	11.71	30.2	99.08	284	.626	49.6	7.69
77.8	15.93	35.3	115.81	381	.840	49.0	7.60
101.9	20.87	40.4	132.55	490	1.080	48.0	7.44
129.0	26.42	45.4	148.95	626	1.380	48.6	7.53

Table IV (Cont.)

Air flow.

Pressure, q		Velocity, V		Velocity through radiator section, V_r		Quantity of air flowing through, Q	
kg/m²	lb/ft²	m/sec	ft/sec	m/sec	ft/sec	l/sec	ft³/sec
13.9	2.85	14.9	48.88	5.2	17.06	28.9	1.02
24.8	5.08	19.9	65.29	6.8	22.31	38.4	1.36
38.9	7.97	24.9	81.69	8.5	27.89	47.8	1.69
56.5	11.57	30.0	98.42	10.2	33.46	57.2	2.02
76.9	15.75	35.0	114.83	12.1	39.70	86.0	3.04
100.5	20.58	40.0	131.23	13.8	45.28	77.2	2.73

Table V.

Experiment 5. Cooling air discharged through 4 rear vents on each side.

Resistance.

Pressure, q		Velocity, V		Resistance, D		Resistance surface, S_D	
kg/m²	lb/ft²	m/sec	ft/sec	g	lb	cm²	in²
25.2	5.16	20.1	65.94	116.3	.256	46.6	7.22
39.6	8.11	25.2	82.68	117.1	.258	44.8	6.94
57.1	11.69	30.2	99.08	252.5	.557	44.2	6.85
77.9	15.95	35.3	115.81	338.0	.745	43.4	6.73
101.6	20.81	40.3	132.22	439.0	.968	43.2	6.70
128.8	26.38	45.4	148.95	543.0	1.197	42.2	6.54

Table V (Cont.)

Air flow.

Pressure, q		Velocity, V		Velocity through radiator section, V_r		Quantity of air flowing through, Q	
kg/m²	lb/ft²	m/sec	ft/sec	m/sec	ft/sec	l/sec	ft³/sec
14.0	2.87	15.0	49.21	4.5	14.76	26.5	.94
24.8	5.08	19.9	65.29	6.0	19.68	33.6	1.19
39.0	7.99	25.0	82.02	7.7	25.26	43.0	1.52
56.6	11.59	30.0	98.42	8.8	28.87	49.0	1.73
77.0	15.77	35.1	115.16	10.6	34.78	59.0	2.08
101.0	20.68	40.2	131.89	12.1	39.70	67.9	2.40

Table VI.

Experiment 6. Cooling air discharged through end of fuselage.

Resistance.

Pressure, q		Velocity V		Resistance, D		Resistance surface, S_D	
kg/m²	lb/ft²	m/sec	ft/sec	g	lb	cm²	in²
25.4	5.20	20.0	65.62	138	.304	54.4	8.43
39.5	8.09	24.9	81.69	215	.474	54.4	8.43
57.1	11.69	29.9	98.10	309	.681	54.0	8.37
77.9	15.95	34.9	114.50	412	.908	53.0	8.22
101.8	20.85	40.0	131.23	531	1.171	52.2	8.09
128.7	26.36	45.0	147.64	660	1.455	51.1	7.92

Table VI (Cont.)

Air flow.

Pressure, q		Velocity, V		Velocity through radiator section, V_r		Quantity of air flowing through Q	
kg/m²	lb/ft²	m/sec	ft/sec	m/sec	ft/sec	l/sec	ft³/sec
6.25	1.28	10.0	32.81	4.0	13.12	22.4	.79
25.0	5.12	20.0	65.62	8.5	27.89	47.5	1.68
56.7	11.61	30.1	98.75	12.6	41.34	71.0	2.51

Table VII.

Experiment 7. Radiator alone.

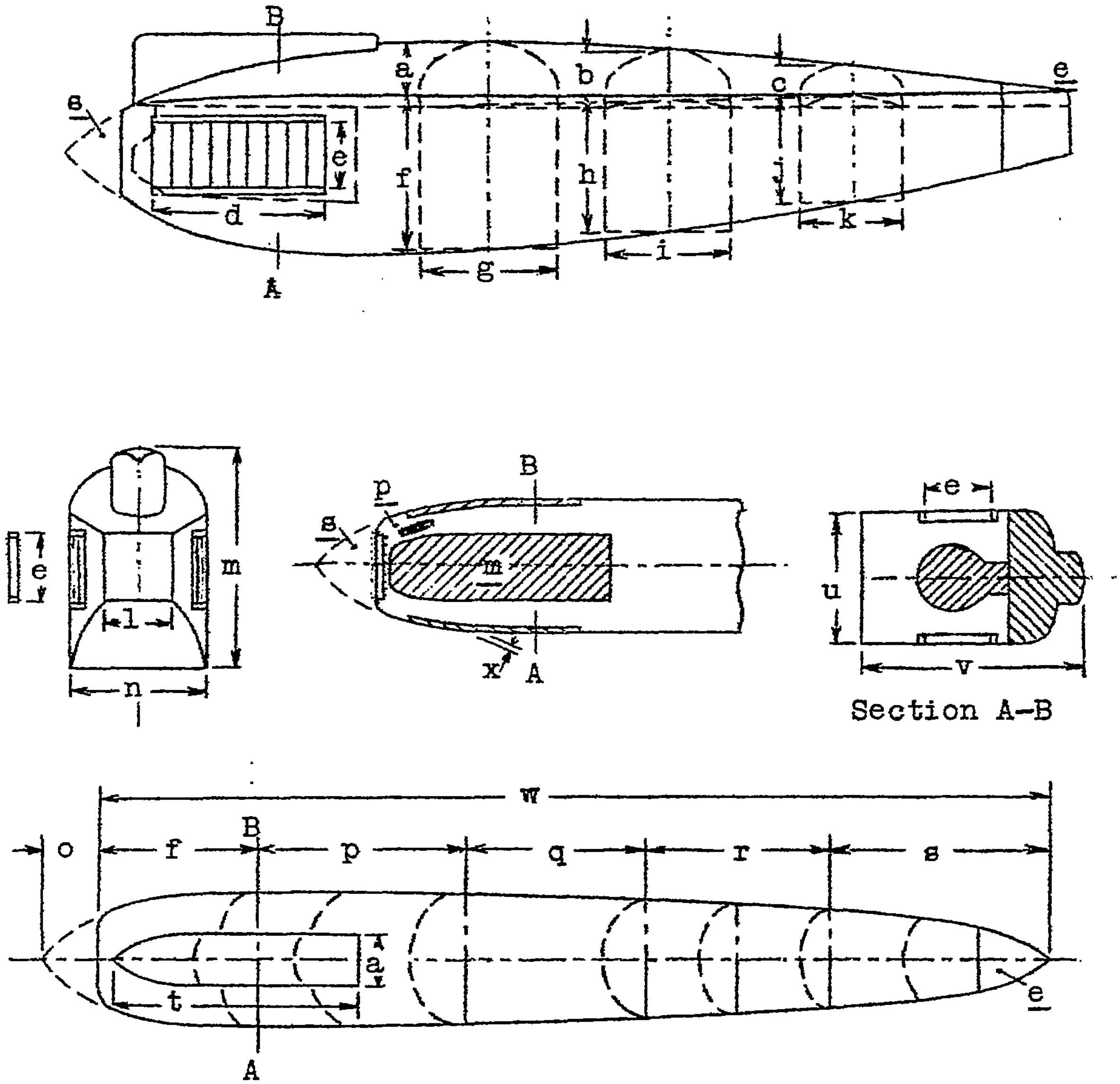
Resistance.

Pressure, q		Velocity, V		Resistance, D		Resistance surface, S_D	
kg/m²	lb/ft²	m/sec	ft/sec	g	lb	cm²	in²
11.3	2.31	13.4	43.96	57.9	.128	51.1	7.92
13.9	2.85	14.9	48.88	73.4	.162	52.8	8.18
20.5	4.20	18.1	59.38	106.1	.234	51.9	8.04
30.0	6.14	21.9	71.85	153.5	.338	51.0	7.91
36.0	7.37	24.0	78.74	183.7	.405	51.0	7.91
47.8	9.79	27.6	90.55	248.0	.547	51.9	8.04

Table VII (Cont.)

Air flow.

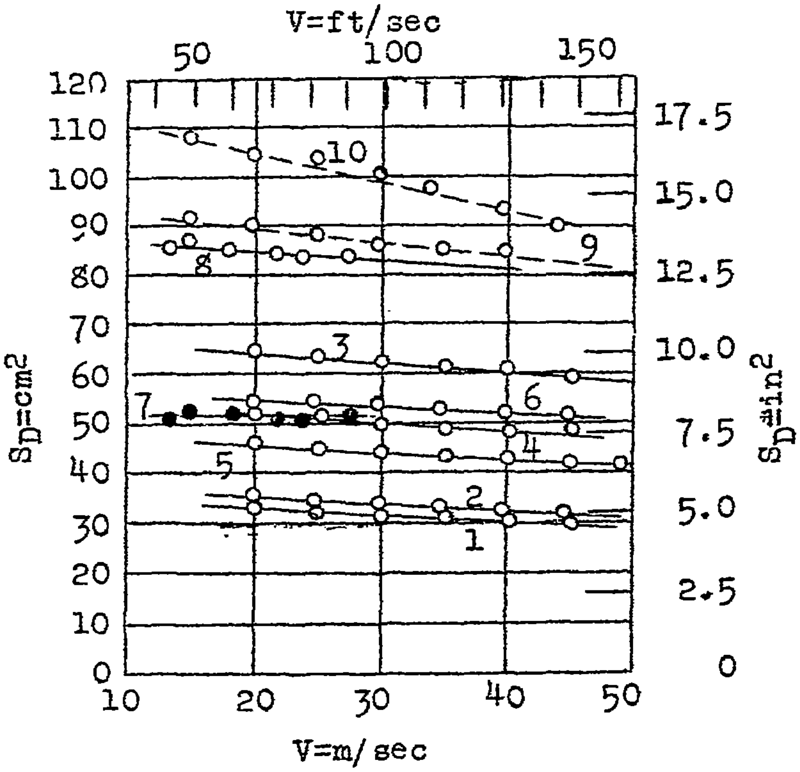
Pressure, q		Velocity, V		Velocity through radiator section, V_r		Quantity of air flowing through, Q	
kg/m²	lb/ft²	m/sec	ft/sec	m/sec	ft/sec	l/sec	ft³/sec
24.6	5.04	19.8	64.96	11.4	37.40	63.8	2.25
34.0	6.96	23.3	76.44	13.5	44.29	75.5	2.67
42.9	8.79	26.2	85.96	15.3	50.20	85.8	3.03
55.2	11.30	29.7	97.44	17.7	58.07	99.1	3.50
70.8	14.50	33.6	110.24	20.4	66.93	114.0	4.03
95.4	19.54	39.0	127.95	23.4	76.77	131.0	4.63
122.0	24.99	44.2	145.01	26.0	85.30	146.0	5.16
137.0	28.06	46.8	153.54	28.2	92.52	158.0	5.58
160.0	32.77	50.6	166.01	30.2	99.08	169.0	5.97



a=58 mm (2.28 in.)
b=50 mm (1.97 in.)
c=33 mm (1.30 in.)
d=192 mm (7.56 in.)
e=77 mm (3.03 in.)
f=176 mm (6.93 in.)
g=148 mm (5.83 in.)
h=156 mm (6.14 in.)
i=138 mm (5.43 in.)
j=124 mm (4.88 in.)
k=114 mm (4.49 in.)
l=75 mm (2.95 in.)

m=250 mm (9.84 in.)
n=151 mm (5.94 in.)
6=63 mm (2.48 in.)
p=229 mm (9.02 in.)
q=200 mm (7.87 in.)
r=205 mm (8.07 in.)
s=244 mm (9.61 in.)
t=270 mm (10.63 in.)
u=150 mm (5.91 in.)
v=246 mm (9.69 in.)
w=1054 mm (41.50 in.)
x=4 mm (.16 in.)

Fig. 1 Model of fuselage of D type airplane



1. Fuselage with hood
2. Fuselage without hood
3. All side vents open
4. Four forward vents open
5. Four rear vents open
6. Discharge through end of fuselage
7. Radiator alone
8. Fuselage with radiator model
9. Fuselage with Rumpler radiator
10. Fuselage with Mercedes radiator

Fig. 2 Resistance surface of fuselage plotted against speed.

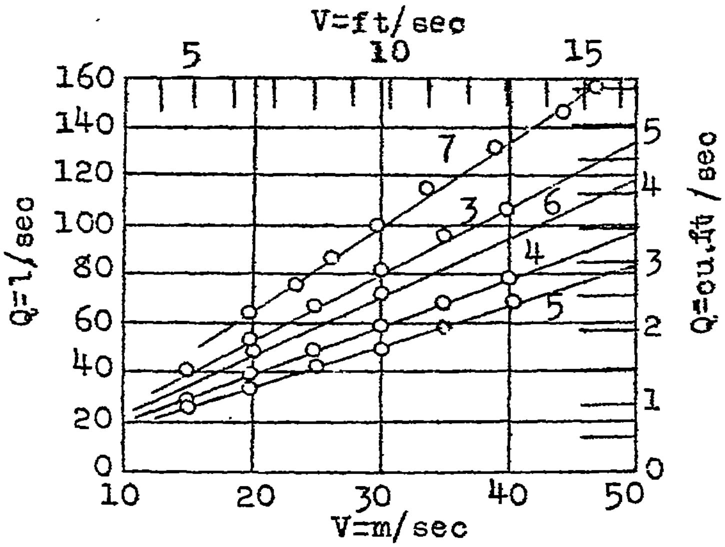
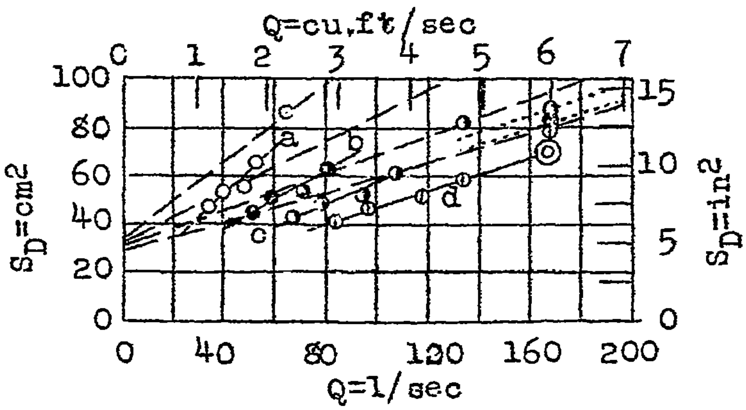


Fig. 3 Quantity of air flowing through radiator plotted against speed



a=20 m/sec (65.6 ft/sec)
b=30 m/sec (98.4 ft/sec)
c=40 m/sec (131.2 ft/sec)
d=50 m/sec (164.0 ft/sec)

Fig. 4 Resistance surface plotted against airflow at different speeds